Forest structure, tree diversity and carbon sequestration in different vegetation types of Anamalai Tiger Reserve

A report submitted to the Tamil Nadu Forest Department

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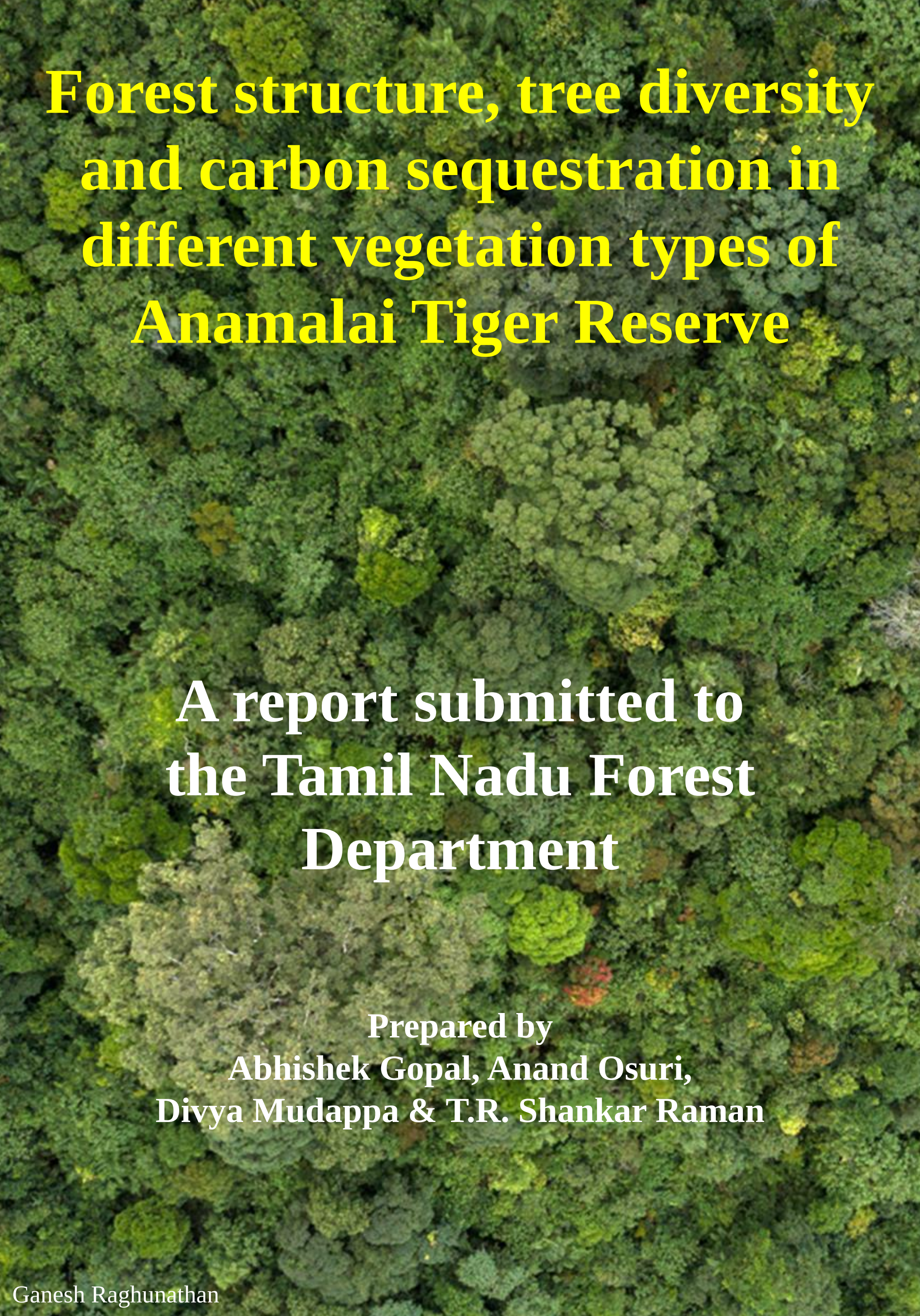

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Research Permit details:

Ref. No. WL5(A)/035933/2016 dated 16/12/2016; Permit No. 74/2016

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Recommended citation:

Gopal, A., Osuri, A., Mudappa, D., Shankar Raman T.R. 2019. Forest structure, tree diversity and carbon sequestration in different vegetation types of Anamalai Tiger Reserve. A report submitted to the Tamil Nadu Forest Department.

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Project funded by:

NatureNet Science Fellows Program

Earth Institute Fellows Program

nature conservation foundation

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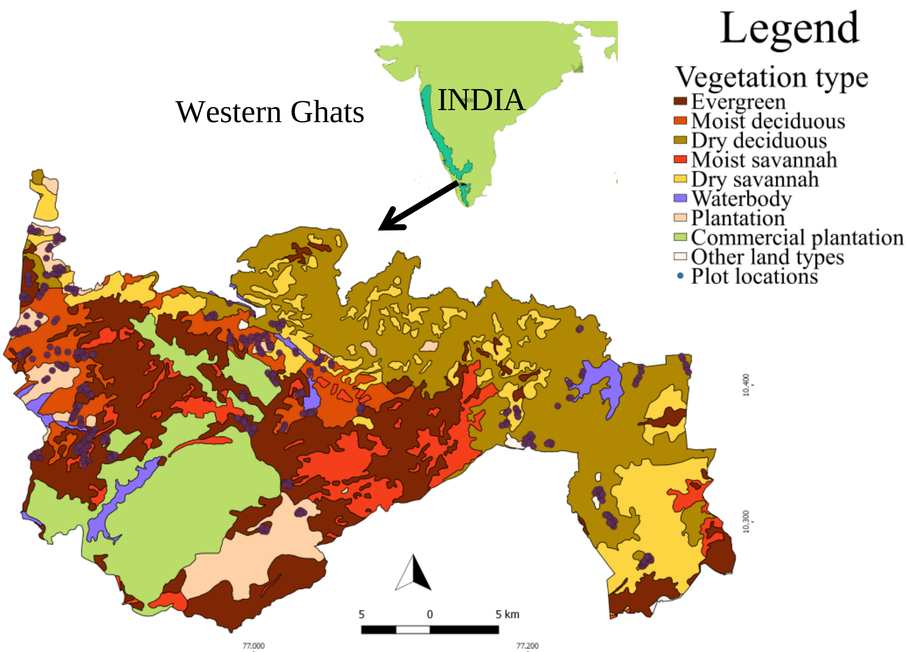
Table of contents

Summary

We conducted a study of forest structure, tree species composition and carbon sequestration in different natural forest and plantation types of the Anamalai Tiger Reserve (ATR). Our first objective was to assess stand structure, floristic diversity and composition, and carbon storage in major vegetation types of ATR. Our second objective was to assess the disturbance level in terms of the prevalence of the invasive *Lantana camara*, and the frequency of dead trees, in these vegetation types. Third, we tested the hypothesis that natural forests offer more stable carbon sequestration than monoculture plantations, using tools of remote sensing. We found that while wet-evergreen forests have greater tree diversity and store more carbon than all other vegetation types, species-poor teak plantations can match moist deciduous forests for carbon storage. However, plantation forests show less temporal stability of carbon capture, and are more susceptible to drought, than natural forests. In terms of disturbance, dry deciduous forests had the highest occurrence of *L. camara* followed by teak and eucalyptus plantations, while *L. camara* was not observed in the sites surveyed within evergreen forests of ATR. Teak and eucalyptus had the highest proportion of dead trees in the girth class 30-90 cm, followed by moist deciduous and dry deciduous forests in the girth class 90-150 cm and >150 cm respectively. Our results offer baseline information that can be useful in periodic long-term monitoring of vegetation and carbon dynamics of the different vegetation types in ATR. The implications of these findings also extend beyond ATR by highlighting the climate risks associated with national reforestation policies that permit the raising of species-poor plantations as compensation for species-rich natural forests.

Keywords: Carbon sequestration; Enhanced Vegetation Index; *Lantana camara*; Natural forest; Plantations; Tree diversity; Western Ghats

Anamalai Tiger Reserve

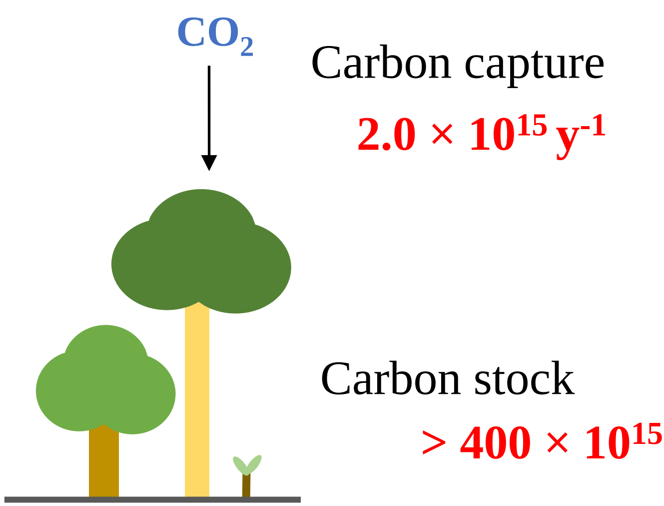


Map of Anamalai Tiger Reserve. Source Renard et al.,2010

The ATR lies in the southern Western Ghats, south of the Palghat gap. It spans over 958 sq. km and has all the major vegetation types found in the Southern Western Ghats. There is a gradient in rainfall from east to west, with the eastern areas being the rain shadow region and having drier vegetation. The terrain is hilly with elevation ranging from 220 m in the north-east to 2,200 m to the south-west. The Reserve has a long history of timber extraction, and plantations of Teak and Eucalyptus have been raised since the late 19th and the early 20th century. These plantations were primarily raised in the western side of the reserve in evergreen and moist deciduous sites. Post the declarations of the reserve in 1976 most extractive measures have been stopped but these plantations continue to remain as the legacy of the past management and exploitation.

Photosynthetic carbon capture & aboveground carbon storage

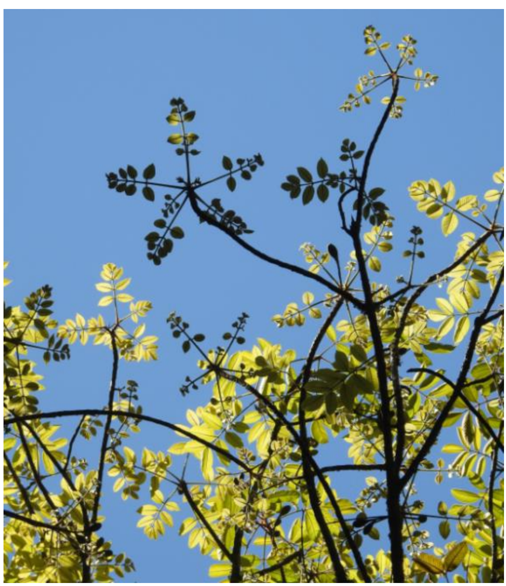
The forest carbon cycle comprises of pools of stored carbon in vegetation and soil, and numerous flows (fluxes) of carbon between vegetation, soil and the atmosphere. In this study, we focus on two main components that affect carbon sequestration by vegetation, namely photosynthetic carbon capture or Gross Primary Production (GPP), and aboveground carbon storage. GPP is the rate of absorption of carbon from the atmosphere by plants through photosynthesis. Globally, forests absorb up to 2 Pg (10^{15} T) of carbon from the atmosphere each year. Some of this carbon accumulates in long-lived vegetation (e.g., woody branches and trunks) and contributes to the aboveground carbon stock, which is around 250 Pg globally, and can range from 200-400 T ha^{-1} in undisturbed tropical forests.



Objectives

Our study in ATR had the following three objectives:

1) To assess stand structure, tree species diversity and carbon storage in evergreen, moist deciduous, dry deciduous, dry thorn and riparian (in the drier areas) forests, and in teak and eucalyptus plantations.
2) To create baseline information of disturbance in ATR in terms of the prevalence of *L. camara*, and the frequency of dead trees, in different vegetation types.
3) To test the hypothesis that species-rich natural forests (evergreen and moist deciduous) show greater temporal stability of carbon, and are more resilient to drought than species-poor plantations (teak and eucalyptus).



Methods

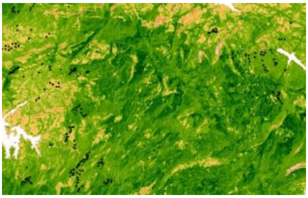
Tree measurements
- Diameter at breast height (D)
- Height (H)
- Species wood density from databases *(ρ)*

Allometric equation

$$\textbf{\textit{Biomass}}\textbf{=}\ AGBest = 0.0673 \times (\rho D^2 H)^{0.976}$$

Aboveground C stock

Remote sensing
Enhanced Vegetation Index (EVI) as a proxy for Gross Primary Production (GPP) or carbon capture via photosynthesis



EVI time series (2000-18)

C capture (EVI)

Temporal stability of C capture (EVI)

C capture (EVI) response to drought

Methods

Forest inventory plots

A total of 397 square plots (20 m side) were placed in the four major natural vegetation types – evergreen (EF), moist deciduous (MDF), dry deciduous (DDF), dry thorn (DTF) – in the riparian forest in the dry areas (RPF), and in the teak (TP) and eucalyptus plantations (EP). Species identity, girth at breast height (GBH), and tree heights were recorded for all trees ≥ 30 cm GBH. Species were identified in the field by experienced data-collectors and field assistants and from collected specimens with the aid of floral keys.

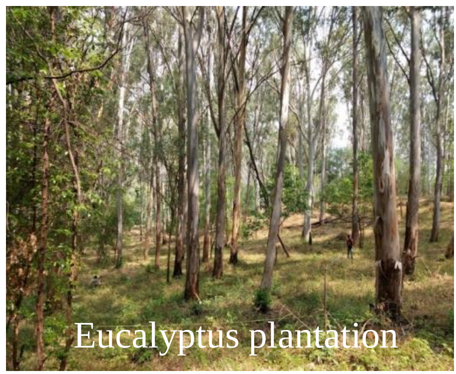
Enhanced Vegetation Index

The Enhanced Vegetation Index (EVI) is an index of photosynthetically active vegetation derived from remotely sensed reflectance. Previous studies have shown that there is a positive relationship between EVI and field-based measures of carbon capture through photosynthesis (GPP). Hence, we used EVI as a proxy to measure productivity in forests and plantations.

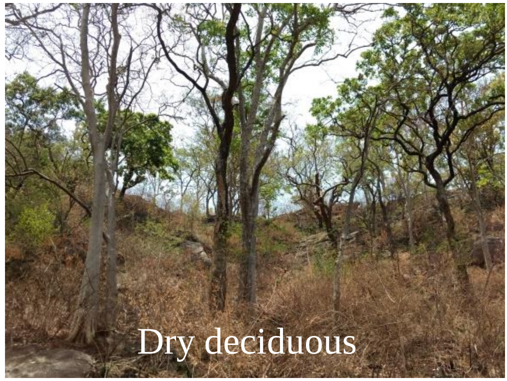
$$EVI = 2.5 \times \frac{(NIR - R)}{(NIR + 6 \times R - 7.5 \times B + 1)}$$

EVI is derived from remotely sensed reflectance in near infrared (NIR), red (R) and blue (B) wavelengths

Vegetation types sampled



Sno.	**Vegetation type**	**Area (km^2)**	**Mean annual precipitation (mm) mean (1 SE)**	**Elevation (m) mean (1 SE)**
1	Evergreen (EF)	271	1879 (11)	1338 (18)
2	Moist deciduous (MDF)	82	1935 (11)	951 (14)
3	Dry deciduous (DDF)	297	1448 (7)	748 (14)
4	Dry thorn (DTF)	141	1542 (7)	921 (12)
5	Forest plantation	69	2012 (6)	1027 (15)



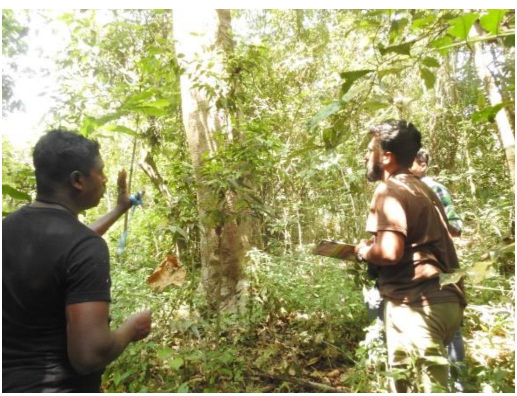
Dry deciduous

Riparian forests

Dry thorn forest

Setting up 20 × 20 m plots

Measuring tree girth and height



Making note of species ID and collecting leaf sample for identification

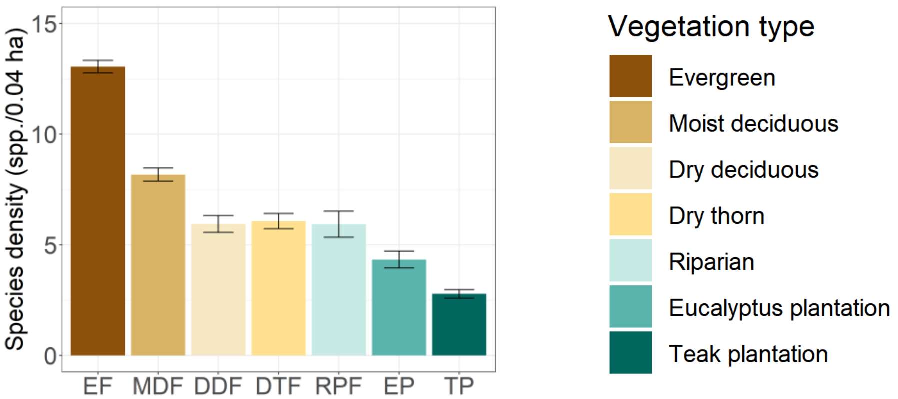
Tree diversity and carbon storage

Evergreen forest had the highest tree diversity and the highest carbon stock

Overall we sampled 6,872 stems across four major vegetation types (EF, MDF, DDF, and DTF), riparian forest in the dry areas, and in teak and eucalyptus plantations. Among the natural forests, *Anogeissus latifolia* (248) had the highest number of individuals followed by *Olea dioica* (136), *Reinwardtiodendron anamalaiense* (107), *Oreocnide integrifolia* (104).

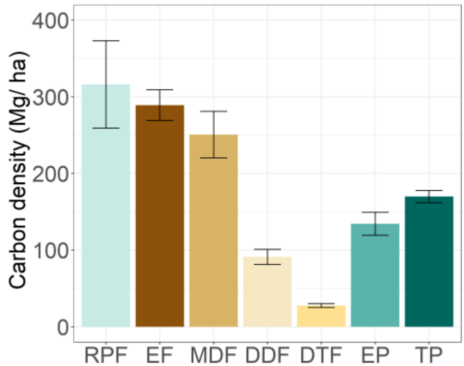
Tree diversity

Tree species richness and diversity were highest in EF and MDF plots, followed by forests in the drier zones. TP and EP had the lowest levels of tree diversity. Tree density was the highest for the EF and EP and lowest in riparian forests and TP.



Aboveground carbon storage per hectare

The aboveground carbon storage per hectare was the highest for EF followed by DF and TP (which had statistically similar carbon densities per hectare), with EP having the least carbon storage among these. However, plantations had higher carbon storage per hectare as compared to DDF and DTF.



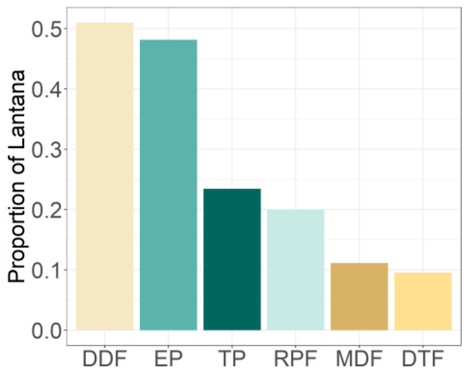
Vegetation type	Num of plots	Mean C density (Mg ha^{-1} ± SE)	Mean basal area (m^2 0.04 ha^{-1} ± SE)	Mean tree density (Trees 0.04 ha^{-1} ± SE)	Species density (*spp.* 0.04 ha^{-1} ± SE)	Shannon diversity index	Simpson's Index of Diversity
Evergreen **(EF)**	117	289.09 ± 19.98	66.05 ± 3.82	21.78 ± 0.58	13.05 ± 0.28	4.64	0.98
Moist-deciduous **(MDF)**	81	250.7 ± 30.33	60.04 ± 4.88	15.56 ± 0.62	8.17 ± 0.30	4.08	0.97
Dry deciduous **(DDF)**	51	91.16 ± 9.83	29.78 ± 2.23	15.00 ± 0.70	5.94 ± 0.38	3.32	0.88
Dry thorn **(DTF)**	42	27.9 ± 2.49	18.60 ± 1.47	15.17 ± 0.86	6.07 ± 0.34	3.03	0.92
Riparian (dry area) **(RPF)**	15	316 ± 57.02	75.47 ± 9.52	11.93 ± 0.85	5.93 ± 0.59	2.79	0.89
Eucalyptus plantation **(EP)**	27	134.32 ± 15.11	36.92 ± 2.83	23.04 ± 2.39	4.33 ± 0.38	1.74	0.56
Teak plantation **(TP)**	64	169.86 ± 8.02	42.17 ± 1.55	13.45 ± 0.69	2.78 ± 0.19	1.31	0.40

Prevalence of *L. camara* and proportion of dead trees

DDF followed by EP and TP had the highest L. camara occurrence. TP had the highest proportion of dead trees.

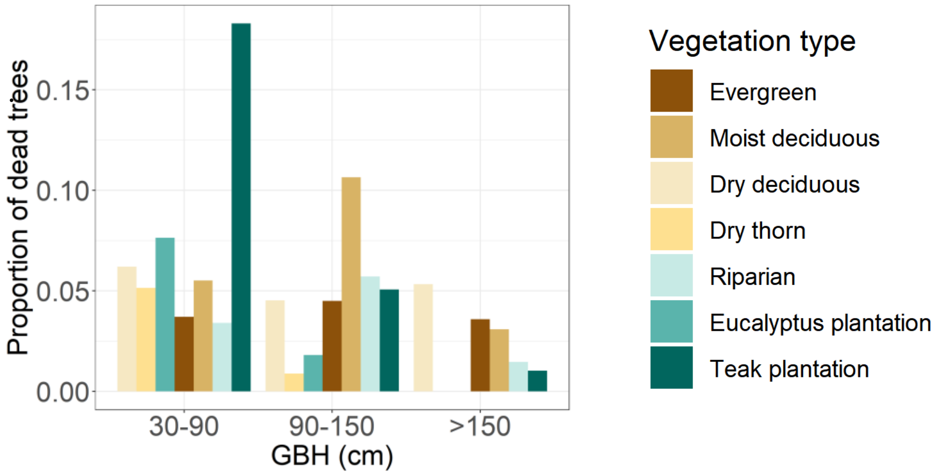
Presence of *Lantana camara*

DDF had the highest occurrence of *L. camara* among the plots surveyed followed by EP and TP and with EF having no occurrence in the sites surveyed.



Proportion of dead trees

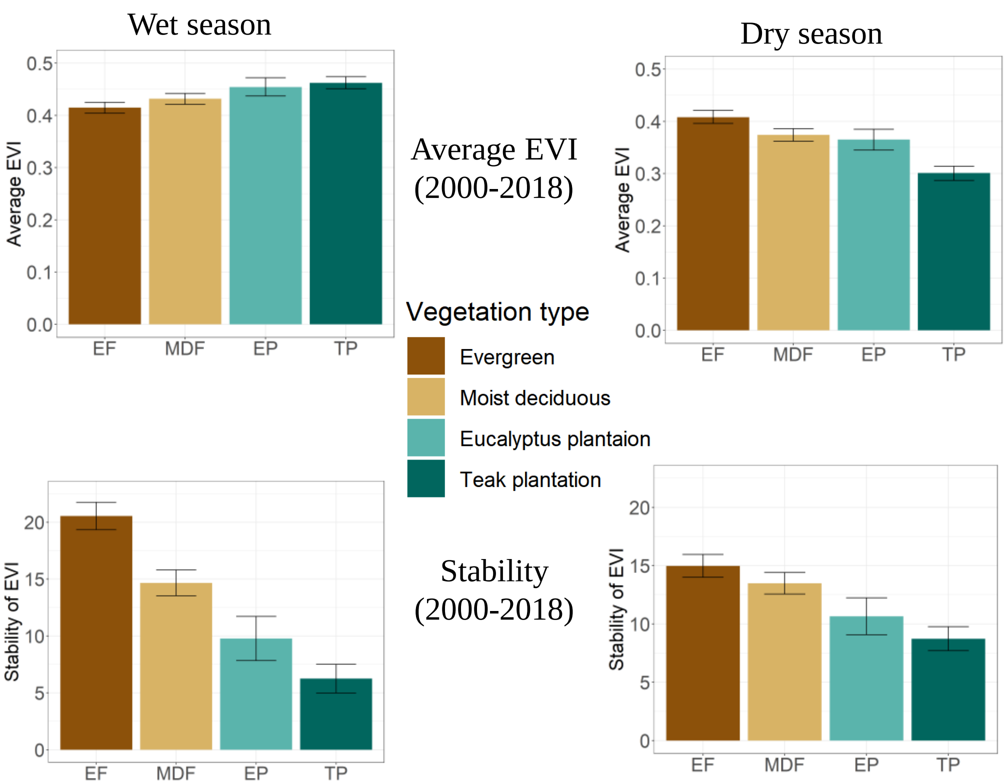
Overall the highest proportion of dead trees was in TP in the girth class 30-90 cm followed by MDF in 90-150 cm and DDF in > 150 cm girth class.



Carbon capture and stability

C capture varied with season and forest type but forests were much more stable than plantations irrespective of the season

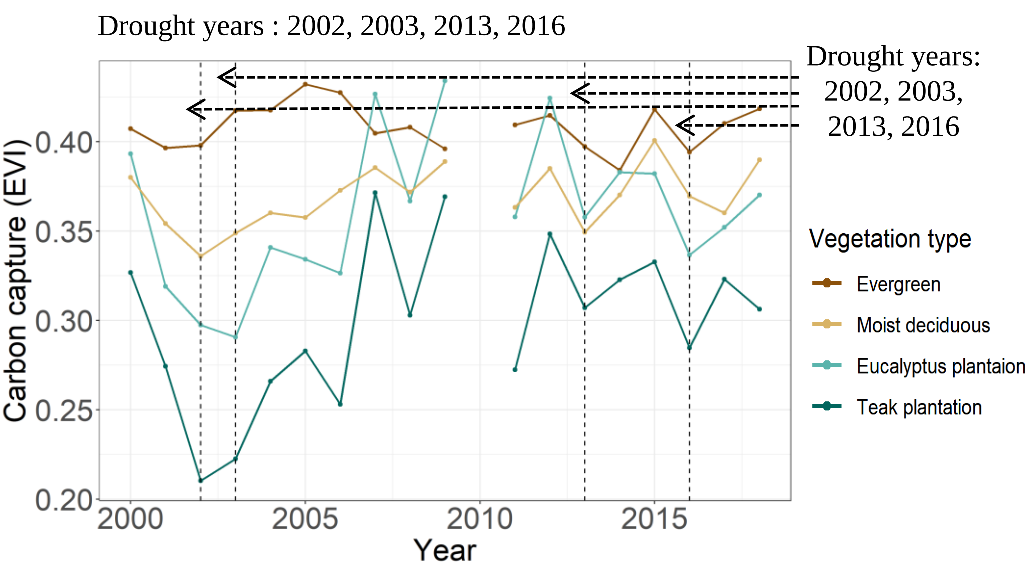
Plantations had 4-9% higher rates of carbon capture during the wet season but 29% lower carbon capture during the dry season. However, carbon capture by plantations was significantly less stable (higher inter-annual variation) compared to the natural forests



Response to drought

Natural forests are more resilient to drought than plantations

Carbon capture by plantations was less resistant to drought (decreased more) compared to forests. Dry season carbon capture declined by 12-14% during drought years in plantations, but only by 2-6% in forests. Plantations are therefore less reliable for carbon sequestration than forests, especially given the predicted increases in drought and climatic variability.



Conclusion

Forest structure, tree diversity and carbon storage

Evergreen forests sustain greatest tree diversity and carbon stocks among all natural and planted vegetation types in the ATR.

Disturbance: L. camara and Dead trees

- The prevalence of *L. camara* was highest in the dry deciduous forests and in teak and eucalyptus plantations.
- Teak plantation had the highest proportion of dead trees

Carbon capture and its stability

While certain plantations can accumulate large carbon stocks, natural forests are more reliable (greater temporal stability and higher resistance to drought) than plantations for absorbing carbon from the atmosphere.

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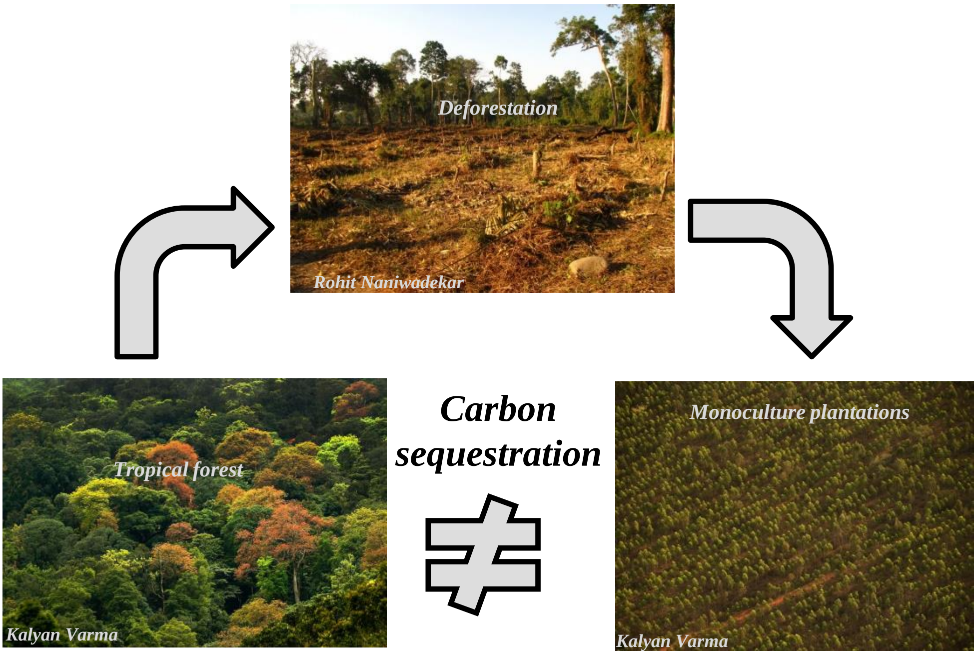
Implications beyond ATR



In India and in other parts of the world, monocultures or species-poor plantations are being raised to offset the forest losses due to deforestation. Tree plantations are also a popular strategy for climate change mitigation. Our findings show that monoculture plantations cannot compensate for natural forests in terms of carbon sequestration, because they show lower temporal stability of carbon capture, and are less resilient to drought than natural forests. Our findings suggest that active or passive restoration of natural forests, and promoting the use of mixed-species plantations, may be more beneficial for mitigating climate change than the current widespread practice of raising monoculture or species-poor plantations.

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Acknowledgement

We are grateful to the Tamil Nadu Forest Department for granting us the permit to do the study and deeply appreciate guidance from Mr. V. Ganesan (I.F.S.), Mr. S. Thangaraj Panneerselvam, and Mr. Peter Prem Chakravarthi Jayam for their guidance and inputs. We are grateful to Rajesh, Sathish, Sundar Raj and Moorthy for assistance during fieldwork. We thank M. Ananda Kumar, M D Madhusudan, Srinivasan Kasinathan and Sreedhar Vijayakrishnan for sharing expertise and technical inputs. We thank Akshay, Ganesh, Ashni, Pavithra, Nishant, Kshama and Stella for all their help and good company. DM and TRSR acknowledge funding from Rohini Nilekani Philanthropies and Arvind Datar, for long-term rainforest restoration and recovery research in the Anamalais.